

The Influence of Atmosphere-Ocean Interaction on MJO Development and Propagation

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LONG-TERM GOALS

The long-term goal of this project is to understand the role of the atmosphere-ocean interaction processes in the initiation, maintenance and propagation of Madden Julian Oscillation (MJO). Better grasp of the atmosphere/ocean feedbacks in the Tropics will allow formulating more accurate parameterizations of the air-sea interface in the forecasting models. It will contribute to improved predictability of the MJO and other coupled phenomena on various spatial and temporal scales.

OBJECTIVE

The objective of this research is to examine how atmospheric fluxes associated with convection influence the structure of salinity and temperature in the oceanic mixed layer in the Indian Ocean. The variability of SST and formation of salinity lenses is emphasized. The feedback of the sea surface variability on the formation of convective cells associated with the MJO will be assessed.

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APPROACH

The three ways coupled atmosphere-ocean-wave model (two-way interactive between COAMPS^{®1} and NCOM; one way interactive with SWAN) is used to examine air-sea interaction in the Indian Ocean during the active and inactive phase of MJO. The model is used for process studies that aim to evaluate atmosphere-ocean feedbacks and their influence on MJO development, and for forecasting of air sea interaction in the Indian Ocean basin and its influence on MJO. The impact of various physical processes and their parameterizations on simulated on predictability of MJO is examined.

The integral part of this project is participation in the field experiment. We will provide forecasting support during the field phase and we will use the experiment data to constraint/evaluate modeling results. The field phase of this project will be associated with DYNAMO, which is the US contribution to the interactional experiment CINDY 2011.

WORK COMPLETED

In the past year, we primarily worked on:

1. Participating in the field phase of DYNAMO by running the daily coupled COAMPS forecasts throughout the duration of the field phase
2. Model validation using the available DYNAMO observations
3. Analyzing the DYNAMO results from COAMPS forecasts and field observations and models obtained through collaborations with other DYNAMO PIs

RESULTS

Coupled COAMPS¹ forecasts during the DYNAMO field phase – model validation and process studies

The 4 day forecasts using the coupled COAMPS were performed daily during the DYNAMO IOP. The spin-up of the model started in mid-August 2011 and the 4 day forecasts were run from October 1 to 2011 to January 15 2012. The results in the graphic form were uploaded daily to the DYNAMO field catalog (<http://catalog.eol.ucar.edu/dynamo/>). The example of the operational forecast results is shown in Fig.1. The model simulations were used for instrument placements, flight planning and interpretation and providing the dynamic context for field observational results. In addition, Sue Chen as a head of the LASP modeling group is coordinating model intercomparisons with other DYNAMO PIs.

¹ COAMPS[®] is a registered trademark of the Naval Research Laboratory.

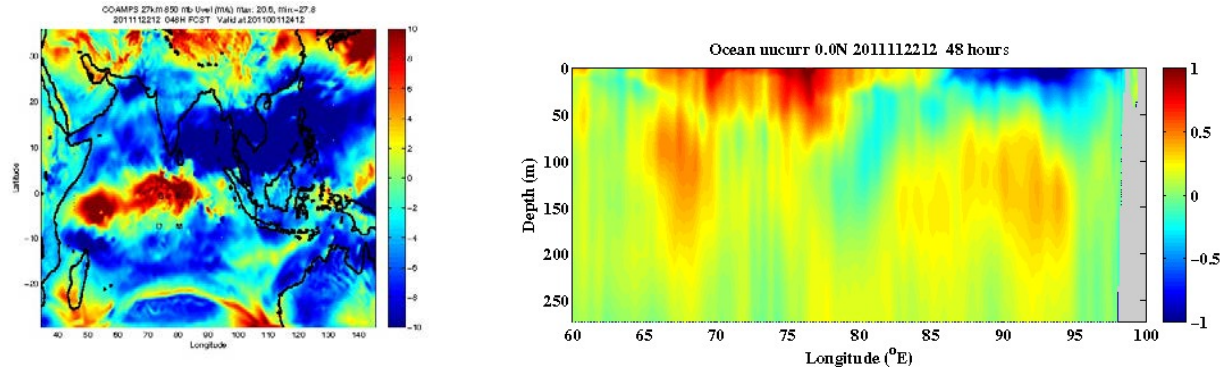


Figure 1: The example of COAMPS forecasts uploaded to DYNAMO field catalogue: 48 h forecast of November 24 MJO event (zonal wind and zonal current).

The DYNAMO was a very successful experiment, with three MJO episodes developing during the observation period. The model forecasts captured the essential features of all episodes. The first MJO that developed on the late October was characterized by relatively large variability, slow increase in magnitude and weak ocean response. The second episode (late November) developed rapidly, triggered by interaction of atmospheric convectively coupled waves and was associated with a strong ocean cooling and development of surface easterly jet that persisted through December. The third episode did not have a clear Indian Ocean signature in the global MJO RMMI index but was clearly seen in the OLR and rainfall observations. It was characterized by large surface wind in the eastern Indian Ocean and very strong ocean response.

General characteristics of the 3 MJO episodes

Fig. 2 shows the synthesis of the ocean and atmosphere behavior during the 3 MJOs observed during DYNAMO, based on different observational platforms. The black and red lines illustrate principal components of eastward moving TRMM precipitation modes with the black line indicating precipitation maximum over the DYNAMO area and the red line indicating the precipitation anomaly west of Sumatra. The corresponding EOF patterns are shown in the right panel. The difference between the three episodes is clearly seen, with the large magnitude and rapid development characterizing the November episode, relatively weaker October episode and convection situated in the eastern part of the Indian Ocean basin in December. Similar EOF decomposition of the precipitation associated with Kelvin waves (not shown here) indicates strong Kelvin wave anomaly during the November event. Surface winds analysis from COAMPS (blue stars in Fig. 2) indicate strong winds associated with November and December MJOs. The thin lines show the ocean response measured by Sea Glider (the data obtained from Adrian Matthews, University of East Anglia). Ocean temperature at 2 m depth (orange) indicates the SST increase and large diurnal variability in the convectively suppressed period in the observation area, and temperature decrease during the active phase of the MJO. The salinity shows the response to the individual precipitation events preceding the active phase (around the day 55), followed by increase caused by mixing associated by the strong winds once the active MJO phase is developed. It will be shown later in this document, that COAMPS simulations indicate that the slow increase of salinity seen in late November and December is associated with advection by the easterly current that developed in response to November MJO.

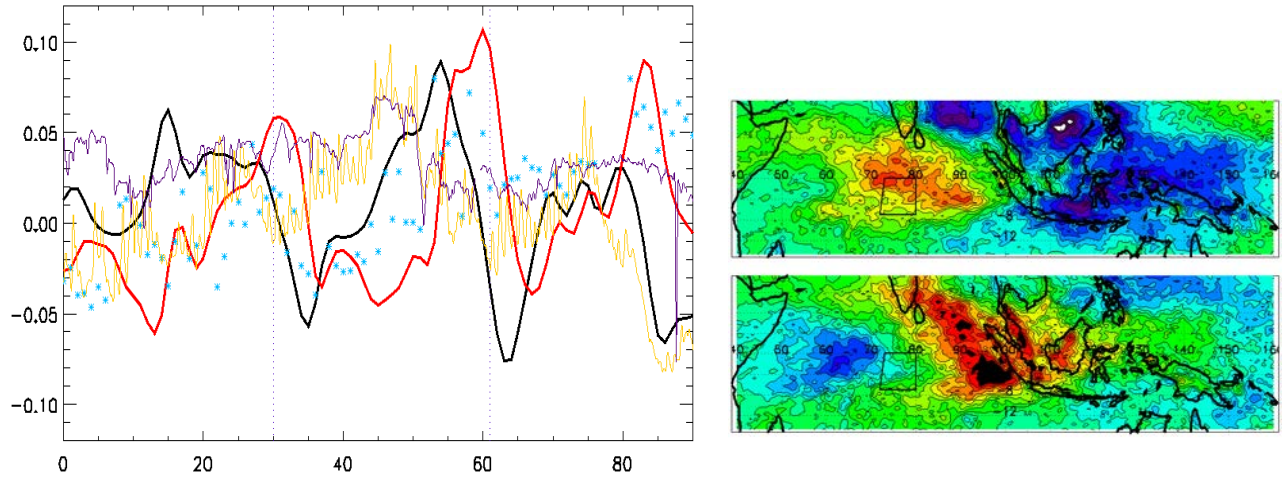


Figure 2: The synthesis of the MJO behavior during the filed phase of DYNAMO. The numbers of the horizontal axis indicate days since October 1 2011. The numbers on the vertical axis correspond to the scaled values of precipitation PCs with the black line denoting the maximum over the central Indian Ocean and red line precipitation anomaly approaching Sumatra. The orange line shows the scaled 2m ocean temperature from the Sea Glider ($T_{2m}-29$)/10. °C, purple line the 2m scaled salinity ($S_{2m}-34$)/10, blue stars indicate COAMPS surface winds ($U_{10m}/140$)

Representation of MJO precipitation in model forecasts

Fig. 3 a indicates that COAMPS forecasts capture the main MJO precipitation features observed in TRMM although some “flattening” of the pattern is observed as the forecast length progresses. Similar behavior of precipitation PCs is can be seen other forecast models used during the DYNAMO. Fig 3b shows the comparison between the 0-day and 6-day forecasts for GFS (data obtained from Augustin Vintzileos) and NICAM (data obtained from Tomoe Nasuno). The results show the even though initially the precipitation pattern in the first MJO was much more variable then in observations while the November event was well represented, the deterioration after 6 days of integration for the November event is quite significant, with the convection in the central Indian Ocean almost disappearing. For GFS some phase shift in the second mode is observed, indicating the MJO is moving slower than in observations.

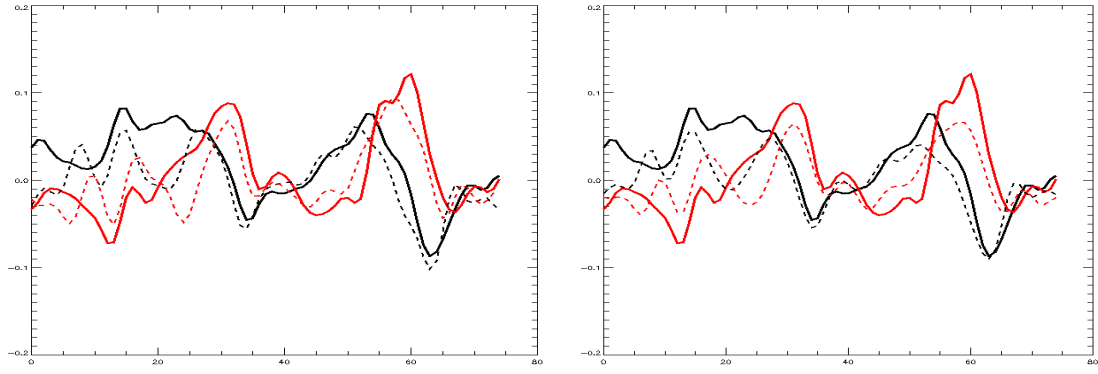


Figure 3 a. PCs of precipitation for the first two MJOs from TRMM (solid line) and from the COAMPS 2 day and 3 day forecasts(dashed lines) .

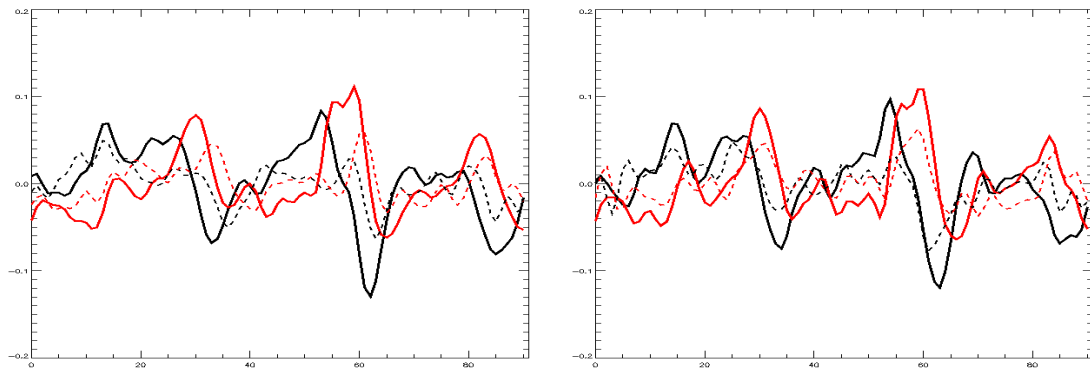


Figure 3 b. PCs of precipitation for GFS(left) and NICAM(right) for the 0 day(0=24h) (solid lines) and 6th day (48-56h) forecasts(dashed lines) .

Atmosphere Ocean Interaction

Fig. 4 further illustrates the differences between the DYNAMO MJO episodes and their interaction with the ocean. In the Fig. 4 the 850mb equatorial winds anomalies are relatively weak during the first MJO and strengthen during the November event. Very strong westerlies develop in December east of the Marine Continent, consistent with the large 2nd precipitation PC seen in Figure 2. In response, the ocean currents are relatively weak in October but a very strong jet develops following the November episode and persists through December. The development of this jet was validated in RAMA buoy measurements and satellite (OSCAR) observations (not shown)

The influence of the easterly jet on the salinity field is illustrated in Fig. 5. COAMPS results indicated that increase of salinity observed in DYNAMO measurements at this time is due not only to salinity mixing caused by strong winds but also to advection of the high salinity water from the Bay of Bengal.

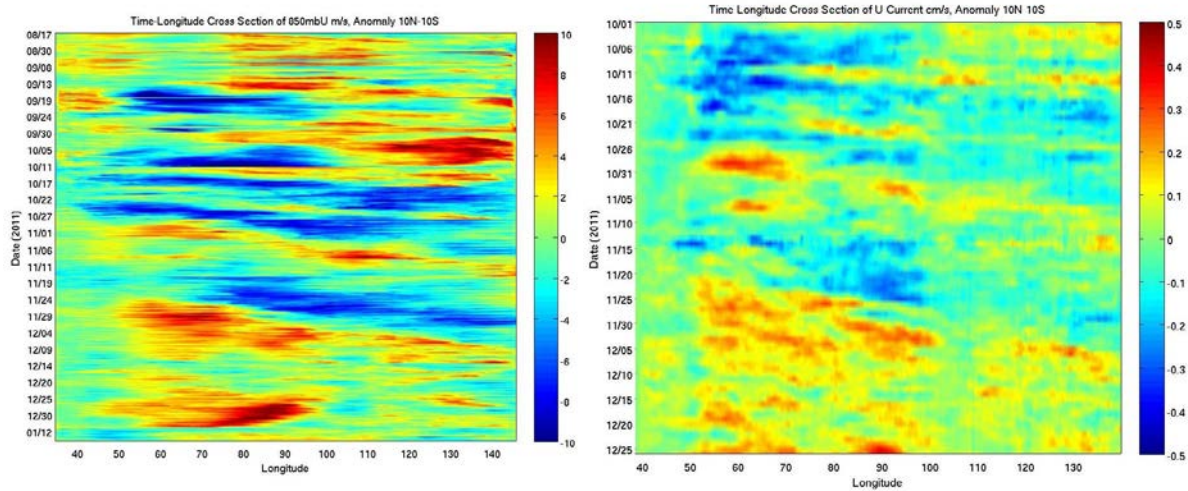


Fig. 4 850mb zonal wind anomaly and zonal surface current for the 3 MJOs observed during DYNAMO field phase from COAMPS 12h forecasts.

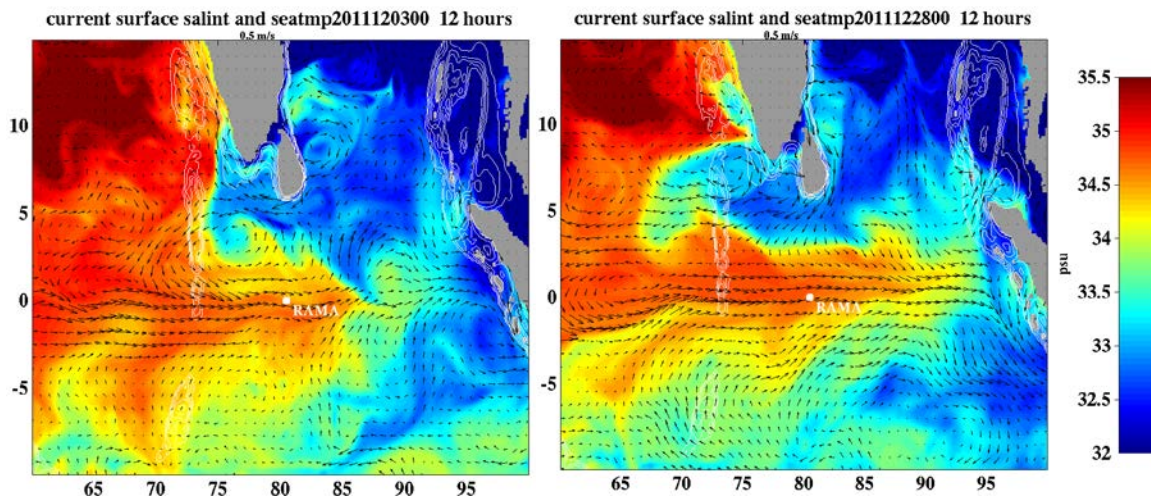


Figure5. The development of easterly jet and its implication for the salinity field, following November MJO (from coupled COAMPS)

Initiation of the November MJO event.

The COAMPS simulations provide an insight into a development of the November MJO. (Fig.6). Satellite observations indicate that preceding the November episode, a Kelvin wave was observed just east of the observational array. At the same time the cyclonic circulation that would later become a tropical cyclone was developed in the eastern part of the basin at about 4N. This cyclonic circulation provided the moisture convergence at the leading edge of the approaching Kelvin wave. In the next 12 hours, as the Kelvin wave propagated eastward and cyclonic circulation propagated westward, the two convective systems merged, creating a very strong westerly burst that initiated the November episode.

Following the merge, the MJO is propagating further westward while the tropical cyclone is developing east of Sri Lanka. Our additional simulations (not shown here) show that dynamic forcing by the Kelvin wave is necessary for the November MJO initiation and that the Kelvin preceding MJO is strengthened by the atmosphere ocean interaction.

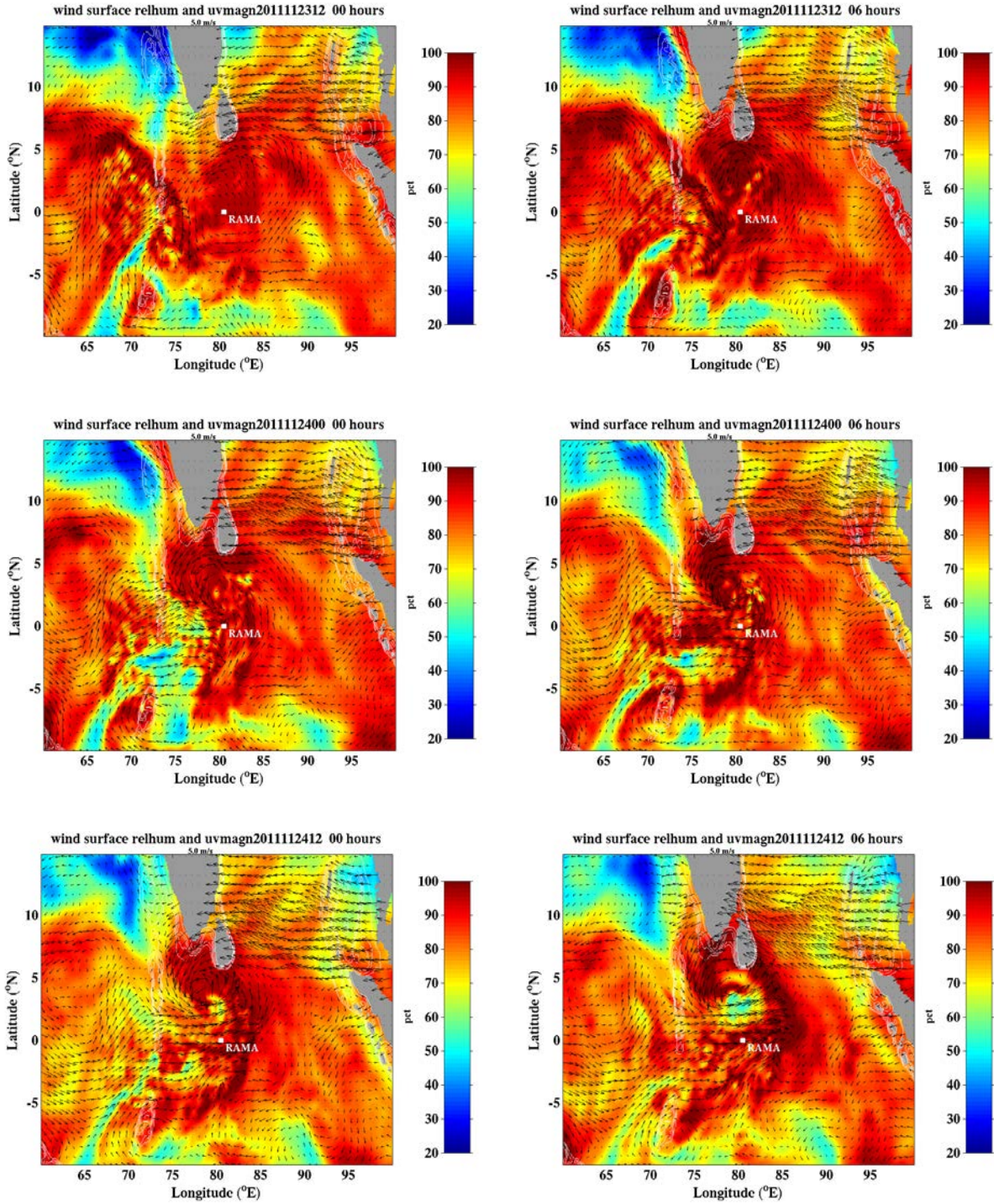


Figure 6. Initiation of the November 24th MJO episode in COAMPS simulations. The arrows indicate surface wind while the colors show the relative humidity. The results are shown every 6 hours starting at noon on November 23 2011.

IMPACT/APPLICATIONS

The project will contribute to the better understanding of feedbacks between convection and atmospheric and oceanic mixed layer. The knowledge gained in this project will allow us to formulate and test more accurate parameterizations, the variance/co variance of coupling, and to improve the forecasting capability of COAMPS® and NAVGEM – especially the NAVGEM coupled to HYCOM. For the DYNAMO field campaign, the model results help to integrate and explain the point observations and to combine them into a coherent description of MJO initiation.

TRANSITIONS

The improvements to coupled COAMPS® that will result from this work and can be transitioned to the 6.2 COAMPS project.

RELATED PROJECTS

This project is a part of the ONR Air-Sea interaction DRI and we collaborate with other PIs involved in this initiative as well as with the wide, international group of researchers involved in DYNAMO/CINDY experiment. Some issues related to impact of the diurnal SST variability on convection are also addressed under 6.1 Tyranny of Scales base project. MJO development problems are also addressed in ONR-DRI 6.1-SeasonGBL.

PUBLICATIONS

Papers:

T. Shinoda, T. Jensen, M. Flatau and S. Chen 2012: Surface wind and upper ocean variability associated with the Madden-Julian Oscillation simulated by the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), MWR, submitted

McLay, J., M. K. Flatau, C. Reynolds, J. Cummings, T. Hogan, and P. J. Flatau Inclusion of sea-surface temperature variation in the U. S. Navy ensemble transform global ensemble prediction system J. Geophys. Res., doi:10.1029/2011JD016937, in press.

Papers in preparation:

Flatau, M, S. Chen, T. Shinoda, T. Jensen, A. Vintzileos, T. Nasuno D. Baranowski P. Flatau and A., Matthews: New technique to evaluate MJO forecasts in limited area models, To be submitted to Mon. Wea. Rev, in Sep 2012

Chen S., M. Flatau, J. M. Schmidt, T. Jensen, T. Shinoda, D. Baranowski: Initiation of November 24 2011 MJO DYNAMO event, as modeled by coupled COAMPS. To be submitted to *Mon Wea Rev* in Oct. 2012

T. Shinoda, T. Jensen, M. Flatau, S. Chen W. Han, and Wang 2012: Intraseasonal surface salinity variability in the Indian Ocean observed by satellite. To be submitted to GRL

Conferences/meetings/seminars

- Chen, S, and M. Flatau, T. Jensen, J. Cummings, T. Shinoda, and P. May. 2012: Model Simulated Equatorial Convection over the Indian Ocean. 13th Conference on Hurricanes and Tropical Meteorology, 15-20April, Ponte Vedra Beach Florida
- Flatau, M. K and S. Chen, T. Jensen, T. Shinoda, 2012: Precipitation in TRMM and in Coupled COAMPS Using the EOF Based Mesoscale MJO Index, 13th Conference on Hurricanes and Tropical Meteorology, 15-20April, Ponte Vedra Beach Florida
- Baranowski, D. and M. Flatau, A. Matthews, S. Chen, T. Jensen, and T. Shin The development of the diurnal warm layer and the ocean mixed layer during different phases of MJO as observed by the iRobot Sea Glider, 2012: 18th Conference on Air Sea Interaction, Boston, Mass, 9-12 July, 2012
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- Chen, S. and C. Fairall, M. Flatau, T. Jensen, J. Cummings, and T. Shinoda, 2012: Comparison of observed bed and model simulated ocean feedback in the Madden-Julian Oscillation 18th Conference on Air Sea Interaction, Boston, Mass, 9-12 July, 2012
- Chen, S.; 2012: COAMPS Real-time Coupled Forecast ONR LASP meeting, Boston, Mass, 12-13 July 2012
- Flatau M. K.; 2012: Precipitation in TRMM and in Coupled COAMPS. ONR LASP meeting, Boston, MA, 12-13 July 2012
- Jensen, T; 2012: Ocean Modeling for DYNAMO ONR LASP meeting, Boston, MA, 12-13 July 2012
- Shinoda, T; 2012: Ocean Variability and Air-Sea Interaction using COAMPS: Plans, ONR LASP meeting, Boston, MA, 12-13 July 2012